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SPECTRAL REFLECTANCE OF SOME PLANT INDICATORS OF SALINE AND NONSALINE SOILS

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ABSTRACT

The task of finding a water supply in an arid region and determining something of its potability can be aided by using various remote sensing techniques for gathering geological, botanical, and terrain data. The objective of this study was to determine if salt-tolerant and salt-intolerant plant species could be distinguished by some unique spectral bandpass in the 0.4 to 1.1 μm spectral region. A number of study sites in Nevada having either salt-tolerant or intolerant plant species were selected. Spectral measurements were made on six salt-tolerant and two salt-intolerant species during June-July when the plants were in full vegetative stage and not under any apparent water deficit stress.

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INTRODUCTION

Man's activities in arid and semiarid regions are restricted by the lack of water. Locating suitable water can be difficult and require substantial resources, particularly when the water is at considerable depth, or must be transported over long distances.

Vegetation is an indicator of plant-available water; however, determining if this source has development potential for man's uses requires additional information regarding its quality and quantity. Vegetation density can provide some clues concerning the presence and availability of water, particularly when seasonal factors are considered. Plant species have been used as indicators of the chemical and physical condition of their habitats in geobotanical investigations. Species indicative of saline soils and saline water, as well as those indicative of nonsaline soils and fresh water, are well known for most

arid regions of the western United States (Richards, 1954; Meinzer, 1927). Although the species salinity tolerances are known, species identification is limited to ground surveys or, by association with known terrain features. From the remote sensing perspective, identification of shrub and grass species in arid and semiarid regions is not possible except on very large scale imagery and then only for accessible areas with some available ground truth information.

The spectral identification of those species indicative of saline or nonsaline soils and waters would facilitate the remote sensing evaluation of soil and water salinity.

OBJECTIVE

The study objective was to determine if the salt-tolerant and salt-intolerant plant species could be distinguished by their spectral reflectance in the 0.4 to 1.1 μm spectrum.

PROCEDURE

Study areas were identified that had varied soil salinities as indicated by the plant species on these soils. The sites exhibited topographic gradients ranging from high elevation alluvial fans or lacustrine wave-cut terraces to lower elevation fans, stream terraces, and depressions or sinks.

Soil samples were collected from the surface horizon, 0 to 15 cm, and from a deeper soil horizon, usually 30 to 50 cm. Samples were analyzed for percentages of sand, silt, and clay using the hydrometer technique. Soil textural names were assigned to the samples according to U.S. Department of Agriculture nomenclature (USDA-SCS staff, 1951).

Samples were also analyzed for electrical conductivity, pH, and selected soluble ions including Na^+. Conductivities (E.C.) of 1:2, soil:water-saturated extracts were determined with a Labline Model MC-1 Mark IV, wheatstone bridge-type conductivity meter. Ionic analyses were made using an Orion Research Model 407A, "Ionalyzer" and specific ion electrodes.

The sodium-absorption-ratio (SAR) and exchangeable-sodium-percentage (ESP) were calculated. Criteria for naming the saline and alkali soils were according to Richards (1954).

The plant species indicative of soil salinity in increasing order of salinity were: *Artemisia tridentata*, *Chrysothamnus nauseosus*, *Atriplex confertifolia*, *Sarcobatus vermiculatus*, *Distichlis stricta*, and *Salicornia rubra*. Sample sites were selected so as to be representative of the species composition, species cover, and soil conditions in the plant community.

Spectral reflectance measurements were made over the range 400 to 1100 nm, in 10 nm increments, using an EG&G Model

550/555 spectroradiometer system with a 15° field of view. Magnesium carbonate was used as the standard reference target. Measurements were made on clear days between 1030 and 1430 local standard time, 19 June to 1 July 1981.

The spectral reflectance signatures of two individuals of the same species were normally measured at a sample site. The similarities of each spectra were determined by visual comparison of the species spectral curves. Chi-square analysis was used for evaluating the differences between individual spectra and the mean spectrum for a species over the 400 to 1100 nm region at the 95 percent level of confidence.

RESULTS

The soil physical analysis shows that the soil textures were sandy clay loams, silty clay loams, clay loams, silty clay or clay with some sand, sand loam, and silt loam soils.

The saline and nonsaline soils were identified from their electrical conductivities and ESP values. Nonsaline soils were those with E.C. less than 4 mmhos/cm and ESP less than 8 meq Na^+/100 grams soil and saline soils were those with E.C. more than 4 mmhos/cm and ESP more than 8 meq Na^+/100 gram soil.

Three soil conditions were identified:

a. nonsaline soils in the 0 to 50 cm soil profile

b. nonsaline surface horizon and saline subsurface horizon

c. saline soil throughout the 0 to 50 cm soil profile.

Salinity conditions at greater depths in the nonsaline soils were unknown; however, salt-intolerant plant species generally have a rooting depth of 2.0 m or more and their presence would indicate the absence of a saline horizon in the soil profile comparable to a critical minimum rooting depth. Detailed chemical and textural soil data are reported by Satterwhite and Eastes (1981).

Plant species were grouped as those occurring on saline soils and those occurring on nonsaline soils. Species found on nonsaline soils were: *Artemisia tridentata* and *Chrysothamnus nauseosus*.

Artemisia tridentata was the common shrub species on well-drained nonsaline soils on alluvial fans. Electrical conductivities in the surface and subsurface horizons were less than 2 mmhos, ESP's were less than 1.0 meq Na^+/100 grams soil, and SAR's were less than 2.0 meq/liter.

Plant species found on saline soils were: *Atriplex confertifolia*, *A. canescens*, *Sarcobatus vermiculatus*,

Distichlis stricta, Suaeda occidentalis, and Salicornia rubra. Soils on which these species occurred had E.C. more than 4.0 mmhos/cm, ESP more than 7 meq Na^{+}/100 grams soil and SAR's were more than 4.0 meq/liter.

The Atriplex confertifolia communities were commonly found on well-drained sites on alluvial fans. The Sarcobatus vermiculatus communities occurred on the lower portions of alluvial fans, on stream terraces, and in the basin areas. Distichlis stricta and Salicornia rubra communities were found just above standing water in permanent lakes, above the high-water levels in ephemeral lakes, and on the immediate flood plains of some streams.

Spectral reflectance data were taken at 16 study sites. Twenty-one spectra were collected for the saline and non-saline soils and 57 spectra for the halophyte and non-halophyte species. Reflectance measurements of in situ soil surfaces were representative of the surficial conditions at the sample sites. Some surfaces had salt crusts, others were mantled with gravel-size particles or dry algal crusts, and some were bare soil.

Spectra for the in situ saline and nonsaline soils are summarized in Figure 1. The mean reflectance curves were calculated from two or more similar reflectance curves in which the differences from the mean curve were not significant at the 95 percent level of confidence.

Generally, the nonsaline soils had low reflectance. These soils were on mid-elevation alluvial fans and on higher micro-relief areas on the valley floor. These soils often had gravel particles on the surface, but the percentage of these particles in the FOV was small.

Most saline soils were from basin areas and stream floodways. These soils were more reflective than the nonsaline soils because of the salts precipitated on the surface and of their finer texture. Spectral differentiation of certain saline and nonsaline soils, particularly those on the middle and lower fans, was not possible because surface gravel and algal crusts on some saline soils masked reflectance differences.

Reflectance spectra of the two nonhalophyte and six halophyte species are shown in Figures 2 and 3. Differences in canopy geometry, foliage density, and shadows in some canopies produced variations in reflectance curves for a species. The mean spectral curve(s) for a species was the calculated average of two or more spectra, for which variation from the mean was not significant at the 95 percent level of confidence.

Mean reflectance curves for the species found on nonsaline soils are shown in Figure 2. The two curves for Artemisia tridentata show a 2 to 3 percent difference in the visible region and about a 10 percent difference in the infrared. The lower infrared reflectance indicates larger percentages of nonleaf areas, and shadowed areas in some shrub canopies. Reflectance curves for Chrysothamnus nauseosus

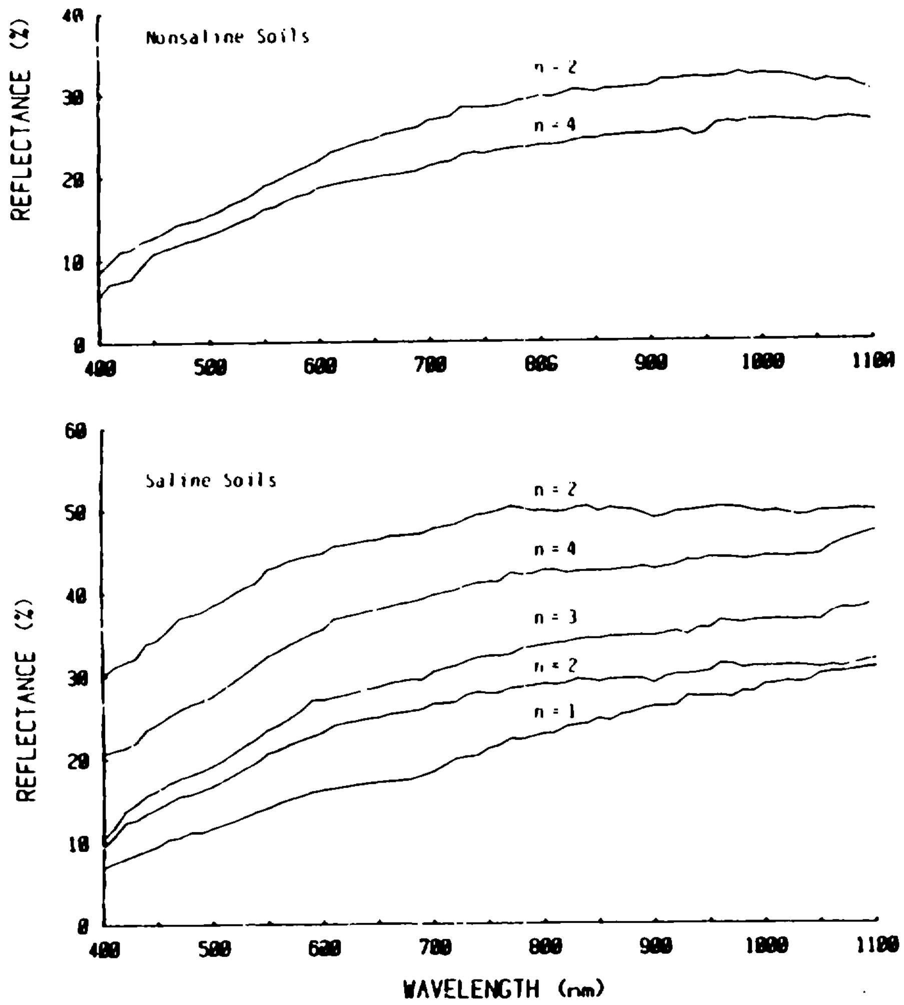

FIGURE 1. MEAN REFLECTANCE CURVES FOR SALINE AND NONSALINE SOILS.
n = NUMBER OF SPECTRA REPRESENTED BY A CURVE.

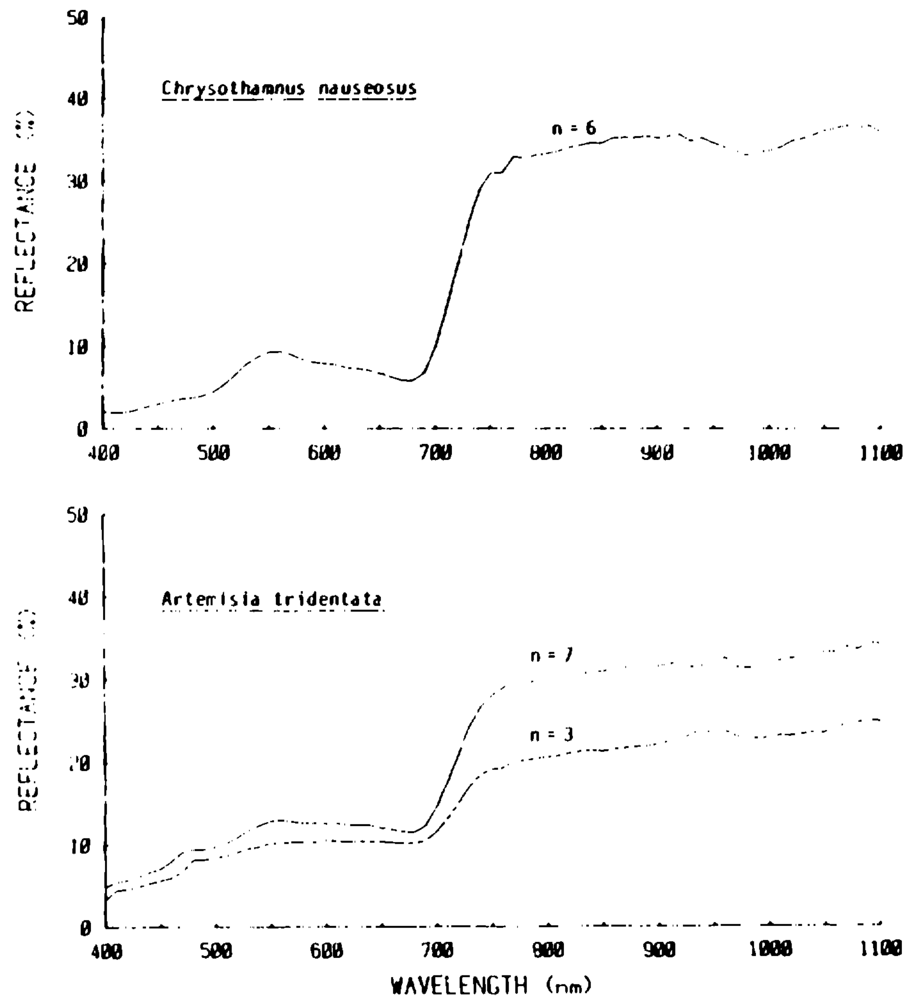

FIGURE 2. MEAN REFLECTANCE CURVES FOR SALT INTOLERANT SPECIES.
n = NUMBER OF SPECTRA REPRESENTED BY A CURVE.

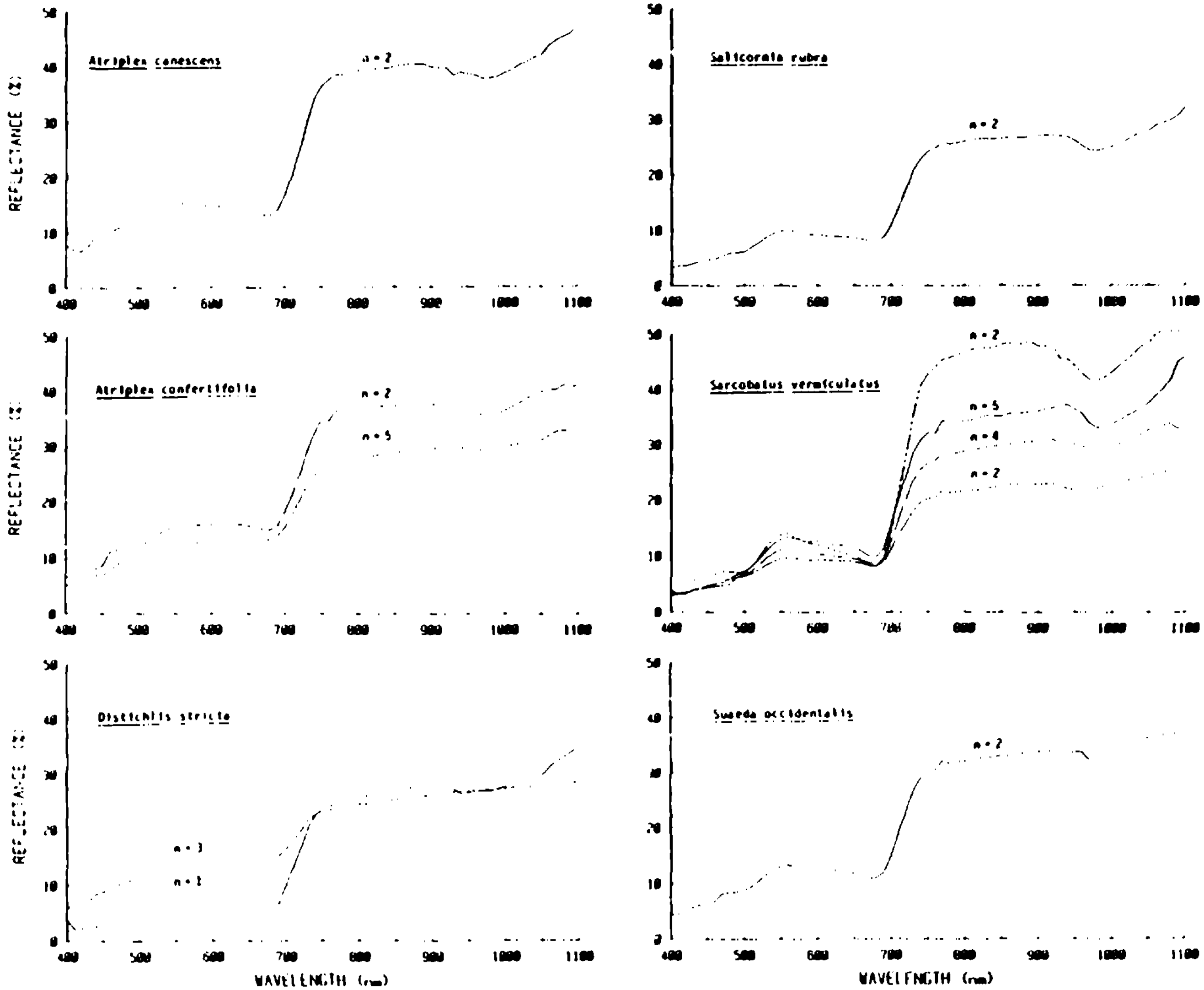

FIGURE 3. MEAN REFLECTANCE CURVES FOR SALT TOLERANT SPECIES. n = NUMBER OF SPECTRA REPRESENTED BY A CURVE.

targets were very similar and only the mean spectral curve is presented. Spectral differentiation between A. tridentata and Chrysothamnus nauseosus was possible using the reflectance contrasts in the visible and infrared regions.

Reflectance spectra for the halophyte species are shown in Figure 3. In the visible region, the halophytes had similar reflectance values, ranging from 10 to 15 percent. Reflectances in the infrared region were greater, ranging from about 20 percent for Distichlis stricta to 40 percent for some Sarcobatus vermiculatus shrubs.

Nonfoliated areas in the plant canopies influenced the measured reflectance curves of several species. Distichlis stricta for example was observed in various growth stages and ground covers. Active growing Distichlis stricta vegetation with more than 70 percent ground cover exhibited lower visible and higher infrared reflectance (the n = 1 curve) than the mean curve (n = 3) which represent those Distichlis stricta targets composed of some senescing grass leaves and a vegetative cover less than 50 percent.

Sarcobatus vermiculatus, a major halophytic shrub in the study areas, had substantial variation in the canopy reflectance spectra. Variation in the visible was 3 to 5 percent, while in the infrared region differences ranged from 20 to 45 percent. Such variations are the result of variable percentages of green biomass, stems, and shadows in the canopies. The field sampling procedures selected individual plants representative of the species growth habit at a study site, while maximizing foliage cover in the FOV.

Comparison of the spectra for the nonhalophytes and halophytes shows that their range of visible and infrared reflectance encompassed each other. Because of the complete spectral overlap, no single distinct spectral region was found to clearly distinguish all non-halophytes from all halophytes. On a species by species basis however, certain salt-tolerant and salt-intolerant species could be differentiated by their reflectance in selected bandpasses. Artemisia tridentata and Sarcobatus vermiculatus could be distinguished by the higher reflectance in the visible region and lower reflectance in the infrared region for the A. tridentata. Atriplex confertifolia and Artemisia tridentata may be separable because of the slightly higher reflectance of A. confertifolia in the visible and infrared regions. The canopy geometries of these two shrubs tend to mask spectral differences that could permit their spectral differentiation. A. canescens is more reflective than Artemisia tridentata in both the visible and infrared regions. Chrysothamnus nauseosus and Sarcobatus vermiculatus could be distinguished in the visible region on the basis of the lower reflectance for C. nauseosus. S. vermiculatus shrubs with dense canopies exhibited higher reflectance than the C. nauseosus, but canopy geometry of S. vermiculatus shrubs varies and tends to mask this difference. Increased absorption in the blue

and red, together with a higher reflectance for *S. vermiculatus* compared to *Atriplex confertifolia*, allow these species to be differentiated. In the infrared region, *S. vermiculatus* with medium-to-densely foliated canopies was more reflective than *A. confertifolia*, but the sparsely foliated *S. vermiculatus* canopies were difficult to distinguish from those of *A. confertifolia*.

Generally, the halophytic species found at lower elevations, i.e., *Sarcobatus vermiculatus*, *Distichlis stricta*, and *Salicornia rubra* ranged in color from light yellowish-green to dark green. Individuals with densely foliated canopies exhibited definite reflection in the green region and high infrared reflectance. For less densely foliated canopies, the spectral characteristics of the stems, shadows, and soil were integrated with those of the foliage.

DISCUSSION

Salinity levels in the soil profiles, 0 to 50 cm, were variable. Generally, salinity levels were highest in soils in the basin areas, lower stream terraces, and floodways where salt accumulated either from the evaporation of ponded water or from capillary water. Saline soils were also found above the valley floors on saline lacustrine deposits. Non-saline soils were commonly found on recent alluvium or aeolian deposits above the valley floors and on well-drained soils where capillary water did not bring salts into the root zone and in areas where salts were readily leached.

Identification of saline and nonsaline rangeland soils has been reported using microdensitometric techniques with black and white Skylab imagery and 70-mm color infrared aerial film (Everitt, et al, 1977, 1981). These authors observed that film density levels were directly related to soil salinities and concluded that the greater reflectance noted for the saline soils was a consequence of reduced vegetative cover because of salinity. This interpretation implies that areas of lower film density represent nonsaline soils. Similar relations were also found in the present study, except where gravels or dried algal crusts serve to make the spectral signature of some saline soils and some nonsaline soils similar. Generally, the bare saline soils in the basin and low-lying areas were brighter because of the precipitated salt crystals which are highly reflective.

A vegetative cover gradient was seen for some highly saline soils, but this was a species-dependent relation. As the soil salinities decreased to those levels tolerated by *A. confertifolia*, *A. canescens*, or *S. vermiculatus*, these species could form rather dense covers, 35 to 70 percent, where sufficient moisture was available. In other areas, *Salicornia rubra* and *D. stricta* formed a dense cover on highly saline soils. Although vegetative cover was approximately inversely related with soil salinities, there appears to be sufficient species adaptability that this trend is applicable only for the high to extremely

high soil salinities. For the low-to-high soil salinities, the salinity-cover relations were affected by other vegetative and nonvegetative parameters. The plant species found at these study sites were indicative of the saline nature of these soils. The species found on saline soils were adjusted along salinity and soil moisture gradients (low-to-high) in the following sequence: _A. confertifolia_, _A. canescens_, _Suaeda occidentalis_, _Sarcobatus vermiculatus_, _D. stricta_, and _Salicornia rubra_. The well-drained nonsaline soils were vegetated primarily with _Artemisia tridentata_, with _Chrysothamnus nauseosus_ as an associate species.

The reflectance spectra taken of the halophyte and nonhalophyte species revealed that, in general, these two groups could not be differentiated by selected bandpasses in the 400 to 1100 nm region. The spectral range of both groups overlapped, thereby precluding any distinct spectral separation.

From a pragmatic perspective, species distribution by salinity gradients and topography can focus attention on those species that require spectral separation because of the juxtaposition of their respective communities. The species that required spectral separation in order to identify their respective communities and predict soil salinity conditions were: _A. tridentata_ and _C. nauseosus_, the nonhalophytic species; and _Sarcobatus vermiculatus_, _Atriplex confertifolia_, and _A. canescens_, the halophytic species. The reflectance for these species shows that certain ones can be differentiated using selected bandpasses. _Artemisia tridentata_ and _S. vermiculatus_ can be separated on the basis of the higher reflectance of the _S. vermiculatus_. _A. tridentata_ and _Atriplex confertifolia_ can be differentiated with less certainty because the contrast between their respective reflectance spectra is small. _A. confertifolia_ was slightly brighter than _Artemisia tridentata_. Their separation can be tenuous because their canopy configuration and background can change the spectral signature of either species. The spectral reflectance curves for these species were similar in shape throughout the measured spectral region and was indistinguishable in some situations. The apparent influence of canopy configuration was best exemplified in the spectra for _S. vermiculatus_.

CONCLUSIONS

1. Considering the halophytes and nonhalophytes as groups, no distinct spectral characteristic was found which distinguished between the two groups. With reference to species, some did have sufficient spectral uniqueness to be identified. This information, when combined with data about expected species spatial distribution, provides a basis for making reasonable estimates of identities.

2. Canopy geometry can significantly alter the spectral brightness levels of some species due to varying percentages of foliage and shadow. These canopy differences could confuse the differentiation of some plant species.

3. Saline soils were generally more reflective than nonsaline soils because of the precipitated salts. Exceptions were saline soils covered with dark-toned gravel particles or dried algal crusts which caused their spectral signatures to appear similar to those of nonsaline soils.

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